Tidal effects in Scalar clouds (numerical simulation) - Ongoing work and future work -

Taishi Ikeda

with Vitor Cardoso, Francisco Duque

Topics

- **Tidally deformed BH**
- **Ongoing work**
  - **Tidal effect in Scalar Cloud**
- **Other application (just idea)**
  - **Geodesic around a tidally deformed BH**
  - **QNM around a tidally defamed BH**

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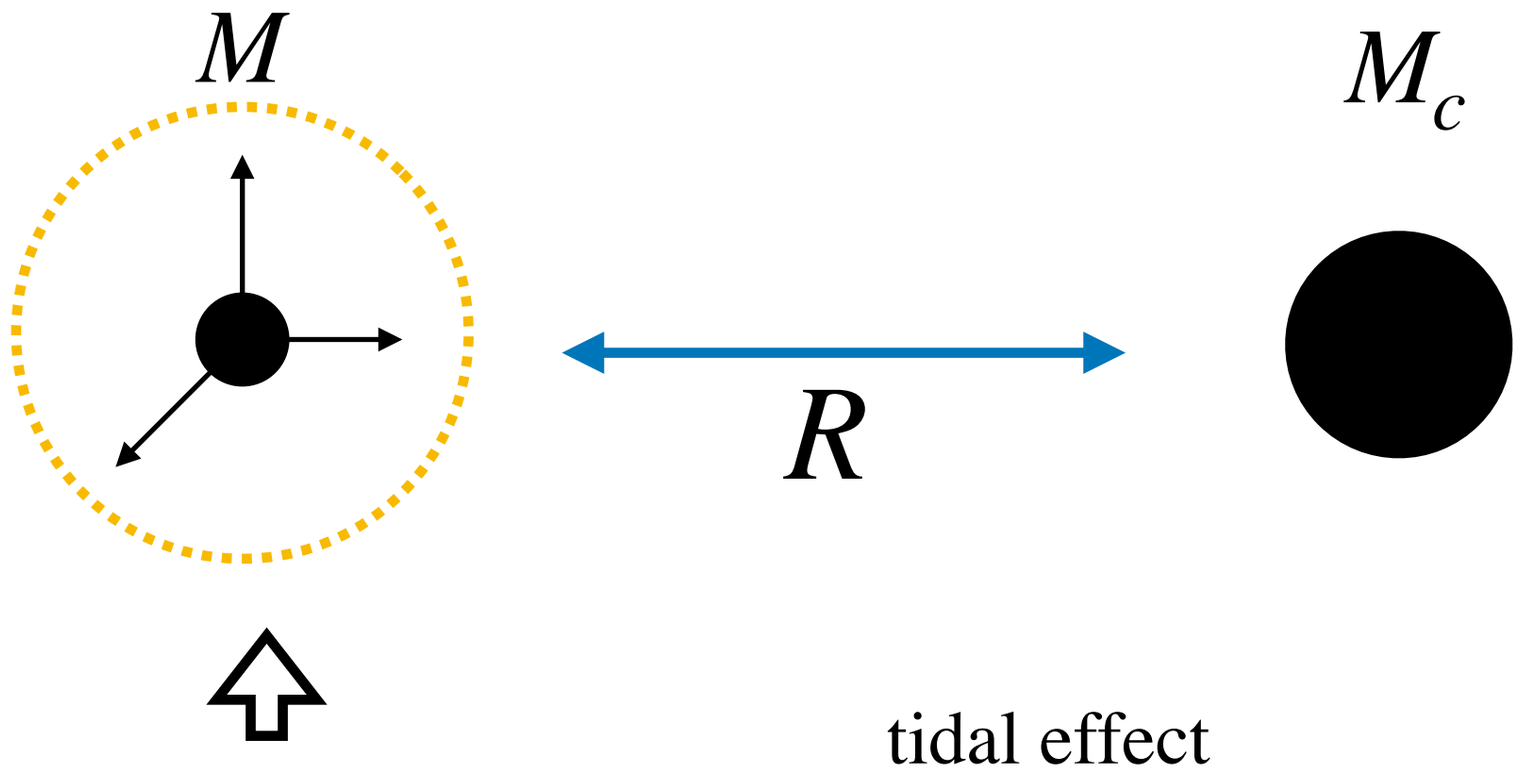
Tidally deformed BH

- How to consider physics around binary BH ?



tidal effect

$$ds^2 = ds^2_{\rm BH} + \sum_m \underline{r^2 \frac{8\pi M_c}{5R^3}} Y^*_{2m}(\theta_c, \phi_c) Y_{2m}(\theta, \phi)\left(f^2 dt^2 + dr^2 + (r^2 - 2M^2) d^2\Omega\right) + \cdots$$

with Regge Wheeler gauge

$\frac{M_c}{R^3}$: characterize the strength of tidal force

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Scalar field around BH

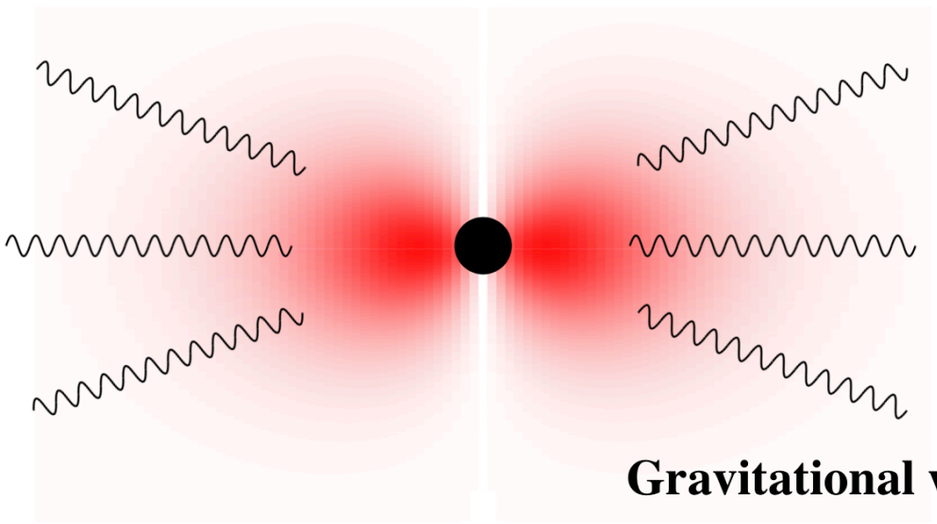
- Light scalar appears in several theories.
  - QCD axion
  - string axion
  - scalar mode in modified gravity et al.

- Light scalar field around BH
  - superradiant instability

$$\omega < m\Omega_{\mathrm{H}}$$

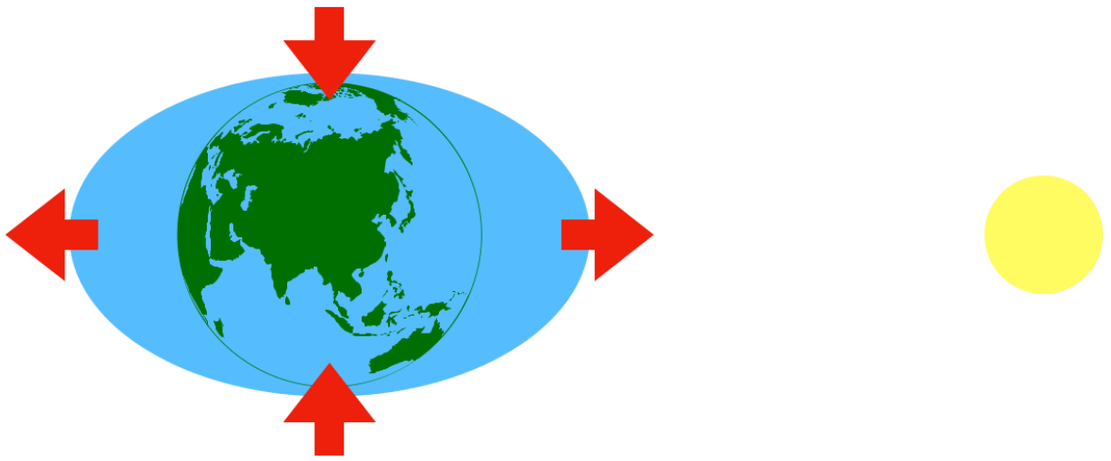
$$\tau = 2\times 10^{4} a \left(\frac{\mu}{10^{-5}\mathrm{eV}}\right)^{-1}\left(\frac{\mu M}{0.03}\right)^{-8} \mathrm{s}$$

  - scalar cloud

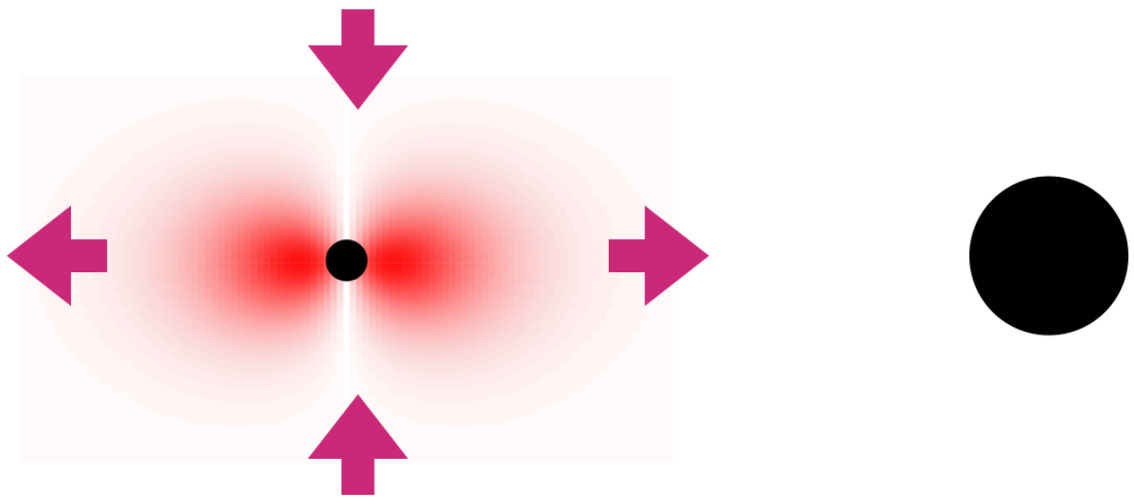


Tidal effect in scalar cloud

- Tidal force on earth



- Tidal force on scalar cloud (Our setup)



Tidal effect in scalar cloud

- Mode mixing (D.Baumann et al PRD99,044001)
  - single BH
    - $(\Box - \mu^2)\Phi = 0$ → non-relativistic limit → $i\partial_t \Psi = \left(-\frac{1}{2\mu^2}\nabla^2 + \underline{V(r)}\right)\Psi$
    - → $|n,l,m>$ $E_{n,l,m}$ cf : QM of Hydrogen atom
  - Binary BH
    - Potential deforms doe to the tidal effect.

$$V(r) \to V(r) + \underline{\delta V(t,r,\theta,\phi)}$$ cf : Perturbation theory in QM

    - mode mixing

$$< n,l,m|\delta V|n',l',m' > \neq 0$$

Tidal effect in scalar cloud

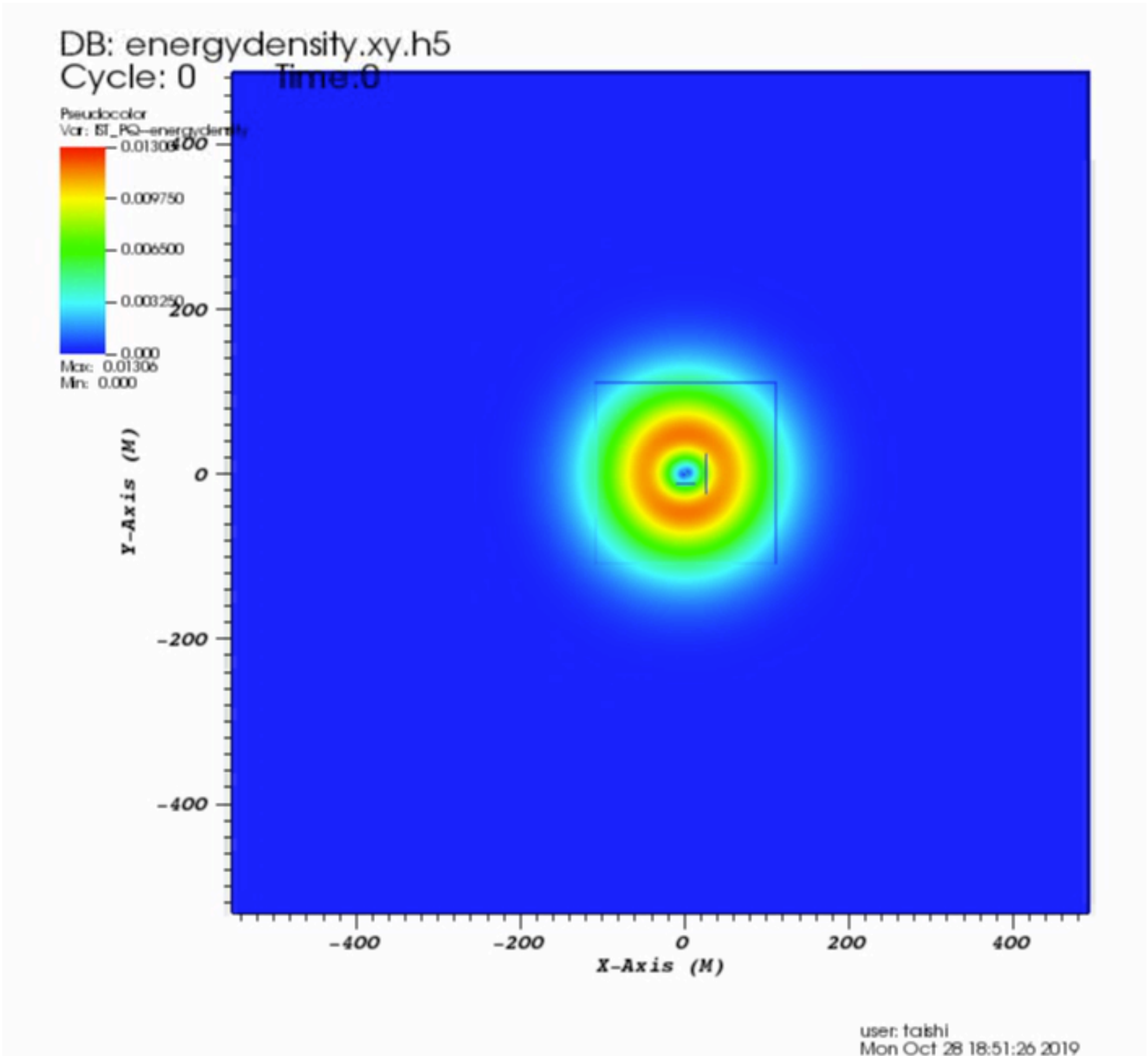
- We analyses the tidal effect by numerical simulation.
  - We want to analyze beyond perturbation theory.
  - What is the final state ?
  - We solved KG eq. on tidally deformed BH.

$$(\Box - \mu^2)\Phi = 0$$

$$ds^2 = ds^2_{\rm BH} + \sum_m r^2 \frac{8\pi M_c}{5R^3} Y^*_{2m}(\theta_c, \phi_c) Y_{2m}(\theta, \phi)\left(f^2 dt^2 + dr^2 + (r^2 - 2M^2)d^2\Omega\right) + \cdots$$

Tidal effect in scalar cloud

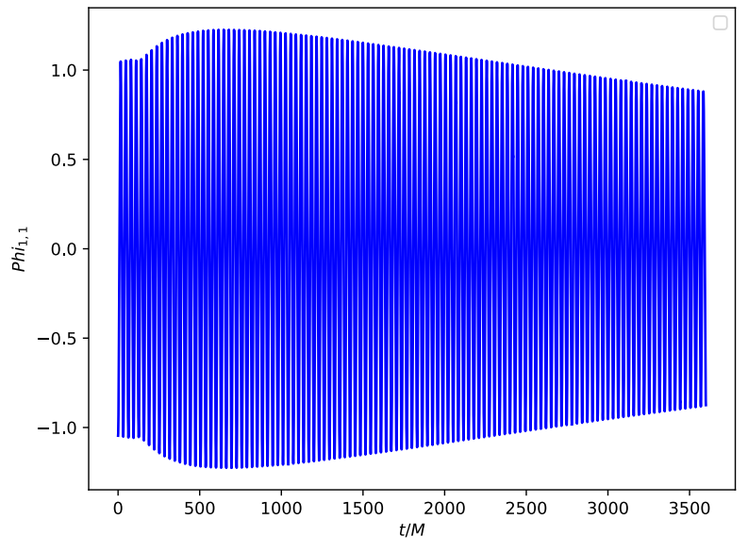
- Simulation1 $\dfrac{M_c}{R_c^3} = 10^{-7} M^{-2}$



Tidal effect in scalar cloud

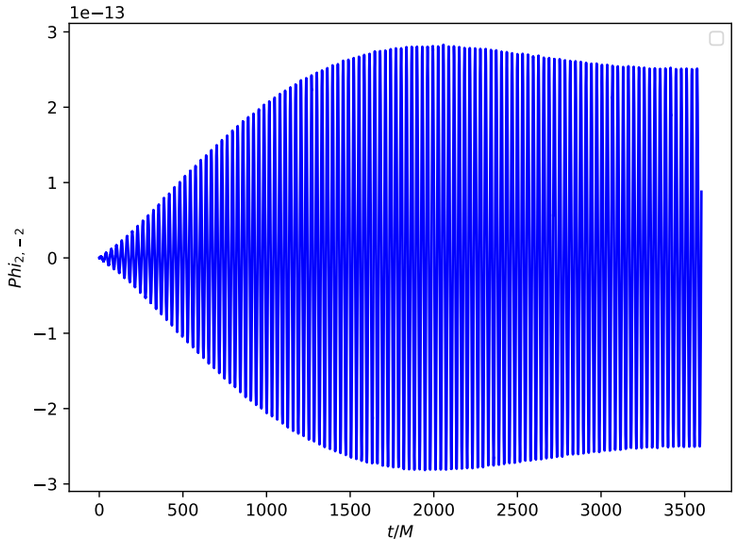
- Simulation1 $\dfrac{M_c}{R_c^3} = 10^{-7} M^{-2}$

$\Phi_{1,\pm1}$

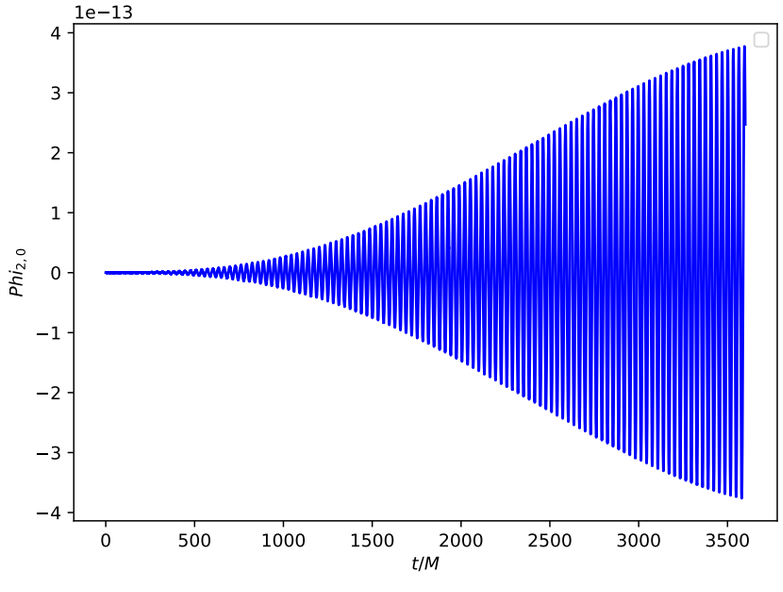


Higher multipoles are excited.

$\Phi_{2,\pm2}$

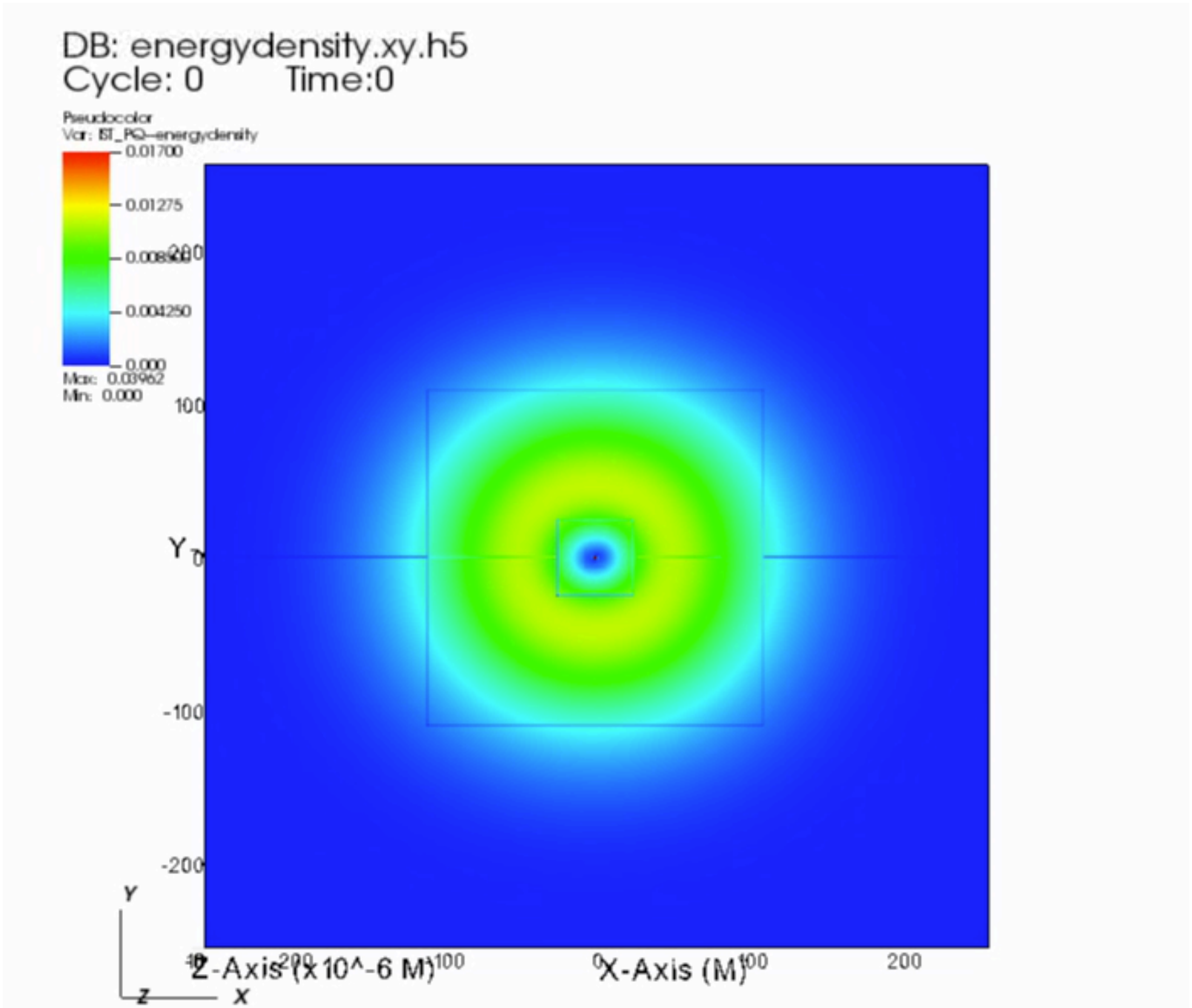


$\Phi_{2,0}$



Tidal effect in scalar cloud

- Simulation2 $\frac{M_c}{R_c^3} = 2 \times 10^{-6} M^{-2}$



Tidal effect in scalar cloud

- Summary
  - We could calculate time evolution of the cloud under tidal effects numerically.
  - Higher multipoles are excited.
  - If the tidal effect is strong, the cloud is destroyed.
- Future work
  - What is the final state ?
  - Is there threshold for the tidal effect above which the cloud is destroyed ?

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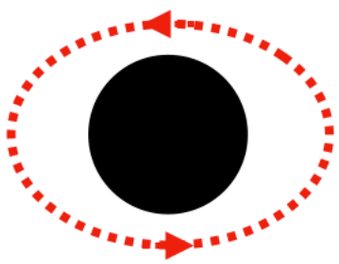
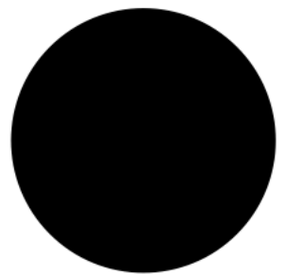
Other application (just idea)

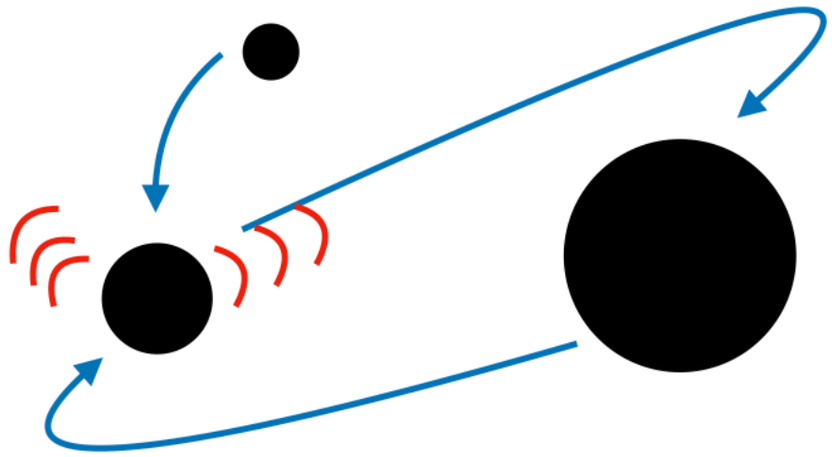
- Geodesic around tidally deformed BH





cf: consistency check with previous our paper

- QNM around tidal deformed BH



Thank you.